

DWR GIS Day 2014
Datums and the Delta Levee Program, by John Wilusz
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1. The goal of this presentation is to provide an overview of survey datums, paying particular attention to how they impact our work in the Levees Program.
2. Learning objective: Hopefully, after this presentation, everyone will know enough about datums to ask themselves these questions.
3. For our purposes today, I am going to keep it simple and define a datum as a point or surface from which distances and directions are measured.
4. For us in the levee program, the datums we are most concerned about are geodetic and tidal datums. And of the two, mostly when we talk about datums we mean geodetic datums.

Bench marks, elevations, topographic mapping, latitude and longitude; these are all based on geodetic datums, either horizontal or vertical. The root word “geo” relates to the earth. Today we will focus primarily on geodetic datums, with an emphasis on the vertical datums NGVD 29 and NAVD 88.

Having said that, tidal datums are important too, especially when dealing with habitat projects that involve tidal marsh. Tidal datums are based, logically enough, on stages of the tides. Although they are quite different, geodetic and tidal datums are often linked together.

5. To further expand on geodetic versus tidal datums (read chart, elaborate). Even though we are going to focus on geodetic datums, we will touch on tidal datums briefly towards the end of the presentation.
6. So, let's start with geodetic datums. Geodetic datums can be divided into two varieties: horizontal and vertical. This slide shows an ellipsoid and a geoid. These are mathematical models used in geodesy and we are going to talk about each one.

The Ellipsoid

Horizontal datums are used to determine latitude and longitude, among other things, and are based on a mathematical model called an ellipsoid. The ellipsoid has an x and y axis, and is an approximation of the shape of the earth. There have been many different ellipsoids in use over the years. In this example, the center of the ellipsoid is shown as being offset from the center of the earth's mass. That's because this particular ellipsoid was intended to be used not for the whole planet, but only for a certain area. You would not know from looking at a picture of it, but the earth is subtly flattened at the poles. In the early days of geodesy, there was general agreement that the earth was not perfectly round, but there was much debate about the orientation of the ellipsoid. Was the earth shaped like a lemon or a mandarin?

The Geoid

Vertical datums are either directly or loosely based on mean sea level at one or more points at some tidal epoch. A geoid is a mathematical model that represents a best fit mean sea level surface, based on gravity measurements. Vertical datums are important to us in the levee program because they are used to determine elevations, such as for levee crowns in the Delta.

7. To further elaborate on the geoid, it can be visualized as the sea level surface extended continuously through the continents. “It is a theoretically continuous surface that is perpendicular at every point to the direction of gravity.” (from *Definitions of Surveying and Associated Terms*).

Notice two interesting things in this sketch: the first is that the geoid and the ellipsoid are not coincident. They are two separate models. We also saw this in the

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previous slide. The second thing is that the geoid is irregular in shape. The geoid reflects the gravity field of the earth.

8. To minimize confusion, we'll talk about horizontal and vertical datums separately. First we'll expand on horizontal datums. The picture of the reference ellipsoid here includes the equator, Greenwich Meridian, and the X, Y & Z axes.

There have been a number horizontal datums in use over the years. With the advance of technology, and continuing refinements in reference ellipsoids, datums have been constantly evolving and improving. The two horizontal datums you are most likely to encounter in the levee program are:

"NAD 27" stands for North American Datum of 1927

"NAD 83" stands for North American Datum of 1983

NAD 27 and NAD 83 use different reference ellipsoids, and consequently produce different values, or coordinates, for the position of the same feature on the earth's surface.

9. Now for an example. Both NAD 27 and NAD 83 are datums in common use today. NAD 83 is the current datum. That being the case, why do we need to be bothered with NAD 27? Why can't we just move into the future and leave the past behind? Here's one reason why. USGS quadrangle maps are based on NAD 27.

This is important to know, particularly if you are using a quad map in conjunction with a GPS receiver in the field. Both map and receiver need to be on the same datum for accurate positioning. That's because the datum directly impacts the coordinate values. This is true whether you are using latitude and longitude or state plane coordinates. If you are using a GPS receiver with a quad map, be sure to set your datum to NAD 27 in the parameters of the receiver.

This is a portion of the USGS quad map (7.5 minute) Sacramento East, photorevised 1980. In the title block, the difference in ground coordinates between the 1927 and 1983 datums is summarized as follows:

"To place on the predicted North American Datum 1983, move the projection lines 14 meters north and 92 meters east..."

Notice the black triangle at the northeast corner of 13 St. and R St.

10. Google Earth is based on WGS 84, which is a global datum. That means the ellipsoid for this datum fits equally well across the planet. Coordinates, such as latitude and longitude, that you get from a Google map will not match those of a USGS quad map. In other words, the same point on the ground will have different coordinates in each map.

Notice the white triangle at the northeast corner of 13 St. and R St. Now we have the same physical feature marked on two different maps. Let's compare coordinates.

11. But remember, there is error in my scaling too. Ground distances in feet per 1" of arc (scaled): $\pm 100'$ latitude, $\pm 80'$ longitude
12. To summarize horizontal datums: (read chart)
13. Let's move on to vertical datums. The vertical datum that comes to mind for most people is mean sea level. Ground elevations and topography are measured perpendicular to this surface. As simple as this concept is, it is challenging and complicated to implement in the real world.
14. The problem here, or at least one of the problems, is that sea level is an irregular surface. To repeat what we learned in a previous slide, "a geoid can be visualized as the sea level

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surface extended continuously through the continents". As you can see in this exaggerated view, that surface is quite irregular.

15. Just like with horizontal datums, there have been a number of vertical datums in use over the years. Vertical datums have also been evolving and improving. The two datums you are most likely to encounter in the levee program are:

"NGVD 29", which stands for "National Geodetic Vertical Datum of 1929"

"NAVD 88", which stands for "North American Vertical Datum of 1988"

Both of these datums are still in use today, and, just like with horizontal datums, each will give different values for the position of the same feature. (Note: there is also a USACE datum in the Delta)

16. NGVD 29 is referenced to 26 tide gauges in the U.S. and Canada. It assumed that all gauges represented the same zero elevation, or mean sea level. However, the elevation of local mean sea level varies from place to place, and NGVD 29 incorrectly forced survey networks to fit between tide stations that had different elevations relative to each other. This introduced error into NGVD 29, error that became increasingly obvious and problematic with the development of GPS.
17. NGVD 29 required a total of 66,315 miles of leveling with 246 closed circuits and 25 circuits at sea level.
18. NGVD 29 was subsequently replaced by the North American Vertical Datum of 1988 (NAVD 88). NAVD 88 (and all benchmarks based upon it) are referenced to a single tide gauge located at Father's Point on the St. Lawrence Seaway in Quebec, Canada. In this way the network was not distorted to accommodate elevation differences between disparate tide gauges.
19. The NAVD88 network is even more extensive than that used for NGVD 29. NAVD 88 also used gravity measurements to measure the geoid.
20. Now for some background on using a vertical datum to establish elevations. Elevations are transferred from one point to the next using a process called differential leveling. A leveling crew starts at a point of known elevation. This point is called a benchmark. The survey crew measures the vertical difference between the benchmark and succeeding points, using the bench mark as a reference. The datum that the bench mark is referenced to will be the datum of the entire survey.
21. The leveling crews that created the networks of NGVD 29 and NAVD 88 used this same process, although they incorporated extremely precise equipment and techniques.
22. Benchmarks, such as this DWR brass disc, are commonly set during high precision leveling work. They are often part of a large network, and are set for use by engineers and surveyors for local projects, like construction and levee work.
23. The federal government sets benchmarks too. Benchmarks like the one shown are part of the national network. These primary stations were set by the National Geodetic Survey (or its predecessor agencies, such as the USC&GS) and are used for local networks, such as those established by DWR. Notice that in this example, the elevation in feet is not stamped on the monument. To find out the elevation of this point you would go to the website of the National Geodetic Survey. We'll have an example of how to do this shortly.
24. Today, precise elevations can also be established using GPS. GPS made it possible, for the first time, to measure between points a great distance apart. As mentioned earlier, it was in doing this that the flaws of NGVD 29 became apparent.
An accurate geoid model is critical when measuring elevations with GPS.

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25. To summarize the difference between NGVD 29 and NAVD 88.
26. This is the homepage for the National Geodetic Survey (NGS). NGS is a branch of NOAA, the National Oceanic and Atmospheric Administration. The NGS defines and manages a national coordinate system known as the National Spatial Reference System (NSRS). The datums we have been talking about are part of this national system.
To find information on survey stations, click on Survey Marker Datasheets under Date & Imagery.
27. And then click on "Datasheets" for information on survey control points throughout the United States.
28. Enter the station name: in this case "B95250"
29. We are in luck. The NGS recognizes the station name and has information on the monument. So we click on "Get Datasheets".
30. At the top of page we see that this benchmark is a "Height Modernization Survey Station". The height modernization survey was a joint effort by DWR and NGS to "modernize" benchmarks in the Delta. In this context, the word "modernize", means to measure control points by the most modern methods in relation to the most current horizontal and vertical datums. This station was last surveyed in 2007, and the vertical datum is NAVD 88, with an elevation of 8.4 feet. That is quite different from the 5.66 feet, NGVD 29, that is shown on the plans. Unfortunately for us, this NGS datasheet does not show an NGVD 29 elevation for this station. Question: is it possible to convert from one datum to another?
31. There is. The NGS has free software called VERTCON, which is also available on their website.
Click on VERTCON from the cascading Tools menu.
32. VERTCON uses a computer model to calculate the difference between the two datums, NAVD 88 and NGVD 29, for a given location. The conversion is sufficient for many mapping purposes, however, it is not the same as physically measuring the benchmarks.
VERTCON returns an NGVD 29 elevation for station B95250 of 6.06 feet. The project engineer confirmed that the elevation shown on the plans, 5.66 feet, is based on actual measurements rather than a computer model. Using actual measurements is always a safer and more accurate approach. Research of historical records at DWR confirmed that B95250 had been elevated in 1988 by differential leveling from a nearby NGS benchmark with an NGVD 29 elevation.
33. One caveat to keep in mind when using VERTCON is that it does not account for subsidence. If the benchmark you are converting has subsided, your VERTCON conversion will be in error. Remember that VERTCON only gives you the modeled difference between *datums* at a given location.
34. Using the correct datum is important not only for levees, but also for ecosystem restoration. It is especially critical to projects that seek to create tidal habitat zones. That's because a relatively small variation in elevation data can determine whether the site is subtidal, mudflat, marsh, or dry upland. This small difference may or may not be within the margin of error of a VERTCON solution, which in the previous example was about 0.4'. It may be necessary to have your project surveyed and tied to a local gage station. In any case, an understanding of acceptable tolerances is the key to success.
35. Up until now we've been talking mostly about geodetic datums. Now we'll touch on tidal datums, which are entirely different. A tidal datum refers to an average height of the

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water level at particular phases of the tidal cycle. On the west coast we have what are called mixed tides, meaning there are two high tides and two low tides each day, with marked differences in the heights of the two waters. Hence the names “lower low water, higher low water”, etc.

On this graph, “0” represents mean sea level, as determined by observations made over a 19 year period. This 19 year period is known as the National Tidal Datum Epoch (NTDE). The NTDE corresponds to a specific lunar cycle, and it is updated by NOAA every 20 to 25 years to account for global sea level change, among other things. The current NTDE is 1983-2001.

It is important to note that this graph does not show the relationship between “0” mean sea level and “0” as established by a geodetic datum, such as NAVD 88. The two are not the same. The “0” shown here represents mean sea level at a unique tidal station. Whatever relationship it has with the world at large is not disclosed on the graph. The relationship between the tidal and geodetic datums must first be established to make this information useful for engineering design and construction over a large area.

36. On this slide we see how the principal tidal datums relate to a beach profile. One important application of tidal datums is the establishment of property boundaries. For example, in California the State typically owns tidelands up to the Ordinary High Water Mark, which in most coastal situations is coincident with mean high water. The lands between mean high water and mean higher high water are known as “swamp & overflowed” lands. S&O lands were granted to the States by the Federal government by an act of Congress in 1850. California subsequently sold its S&O lands to private parties. Much of the land in the Delta was sold by the State as swamp and overflowed land.
37. This has been a pretty light treatment of tidal datums. If you’d like to learn more, a great source of information is the Tides and Currents page of the NOAA website, at <http://tidesandcurrents.noaa.gov/>

Advantages of NAVD88 Datum

http://www.cd.water.ca.gov/surface_water/NAVD88_Advantages.cfm

NAVD88 New Vertical Datum in the Delta

<http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/DSM2UsersGroup/Preseasonfloodmtg110206final.pdf>

Frequently asked questions about the National Geodetic Survey

<http://www.ngs.noaa.gov/faq.shtml>

Geodetic Tool Kit (transformation software) and Survey Mark Datasheets

<http://geodesy.noaa.gov/>

California tides and gage stations

<http://cdec.water.ca.gov/>

Tidal Datums

http://tidesandcurrents.noaa.gov/datum_options.html

http://tidesandcurrents.noaa.gov/publications/fantastic_tidal_datums.pdf